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THE EFFECT OF DIFFERENT TIMES OF PLOWING SMALL-GRAIN STUBBLE IN EASTERN COLORADO.

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INTRODUCTION.

The data here presented have been obtained during the past six years at the Akron (Colo.) Field Station of the Bureau of Plant Industry. Though these data are from the Akron station only, they agree in the main with those obtained from other stations, and it is believed that the principles deduced are of general application in the Great Plains.

The time of plowing is one of the most frequently discussed subjects and one on which very few authoritative figures can be obtained. This is not due so much to a limited amount of experimental work as to the seemingly contradictory results obtained. In the following pages the major portion of the discussion will be confined to the time of plowing for spring wheat, which, although a crop of secondary importance in this region, was selected because a series of moisture determinations has been made in connection with its growth. Oats and corn have given similar results, so that wheat may be taken as representative of the spring crops.

The object of presenting these data at this time is not to advocate either spring or fall plowing, but to show, if possible, correlations between precipitation and time of plowing. Six years' records, with yields no more consistent than those here presented, are not sufficient justification for forming conclusions and laying down hard and fast rules in agriculture. In a climate where the precipitation is as erratic as it is in eastern Colorado there are very few farming operations which can be done successfully by rule of thumb, and this is especially true of any rule for time, depth, and method of plowing.

By many who have had little or no experience in actual farming in the semiarid regions of the West annual plowing is considered as the most necessary of the cultural operations, but this is not substantiated either by the experience of many successful farmers or by the records from experimental work. A smooth, deeply plowed, well-harrowed surface looks well and gives the impression of carefully conducted farm operations, but may prove detrimental in crop production. The smooth, finely pulverized surface is readily subjected to blowing, and the loose, unpacked seed bed may be quickly dried by the rather free circulation of air through it. Stubble left on a field may give it an unkempt appearance, but at the same time may be of value in catching snow or in preventing the soil from blowing. There may be a great deal of misdirected labor expended in preparing a seed bed, which defeats the object sought rather than aids in the production of a crop.

Moisture is generally considered the most important factor in crop production in eastern Colorado. Its conservation is the primary object in cultivation. Experience has shown that on this soil weeds are the greatest robbers of moisture, and their control must always be considered. Stubble, weeds, and uneven ground are the common means of retaining snow and holding a large part of the winter precipitation. In deciding when a field shall be plowed, the question whether a greater amount of moisture will be accumulated by holding the snow that falls than will be dissipated by the growth of weeds must be paramount. It can best be decided by the man on the ground. In answering this question several factors must be considered, namely, the amount of moisture already in the soil that may be lost through weed growth, the probable time before the weeds will be killed by frost, the possibilities of increasing the water in storage in the soil by holding the snow that may come, the danger of soil blowing if the stubble and weeds are removed, and the distribution of the farm labor.

In the following pages the importance of these factors will be considered and the experimental evidence bearing upon them will be given. It is believed that a careful consideration of these data will assist the farmer in determining the best time to plow.

In order to interpret properly the following data it is necessary to consider the amount and distribution of precipitation during the time these investigations have been in progress. The precipitation records and crop yields of the six years from 1909 to 1914, inclusive, should be studied together if any correlation is to be seen between the distribution of precipitation and the time of plowing.

PRECIPITATION.

Table I gives the monthly precipitation for 10 years from 1905 to 1914, inclusive, which is the period covered by continuously recorded observations at Akron, Colo., both by the United States Weather

Bureau and the Bureau of Plant Industry. A study of these records shows the great variation in monthly and annual precipitation. The experimental data following are for the past six years, 1909 to 1914, inclusive. In two of these years the precipitation has been above the normal, as determined from the entire record. In 1909 the total was 2.2 inches less than the recorded maximum. In four years of the six it has been below normal, the precipitation of 1911 being the minimum recorded. Thus, in the six years we have had nearly the maximum and the minimum amounts of water that may be expected.

A heavy monthly precipitation usually means that a considerable amount falls at one time and penetrates to a depth where it is not lost by evaporation but can be used by plants. The exceptions to this are when the precipitation falls as torrential showers with a high percentage of run-off and shallow penetration, or when it comes as light snow, which is blown off. A light monthly precipitation indicates that the greater part of it falls as light showers or as snow flurries. Under such distribution most of the moisture is lost by evaporation and very little, if any, penetrates deeply enough in the soil to be held until used by the plants.

TABLE I.—*Monthly and annual precipitation and normal monthly and annual precipitation at Akron, Colo., 1905 to 1914, inclusive.*

[Precipitation record, in inches, for the years 1905 to 1909, inclusive, from the reports of the United States Weather Bureau.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1905	0.37	0.32	5.45	4.55	4.37	2.14	3.82	0.86	0.83	1.73	0.12	0	24.56
1906	.25	.26	1.51	4.22	3.32	1.20	2.46	1.26	1.00	1.90	1.56	0.08	19.02
1907	0	[1] T.	.43	1.74	3.30	3.26	6.06	5.13	1.86	.02	1.00	.60	23.40
1908	0	.34	T.	1.70	3.57	2.35	3.40	1.62	.22	3.20	2.00	T.	18.38
1909	T.	1.38	3.06	.40	1.87	3.32	4.61	3.77	2.16	.78	.48	.55	22.38
1910	.05	.16	.26	3.96	2.06	1.38	1.47	3.72	3.81	.05	.12	.32	17.36
1911	.60	.44	.06	2.63	1.15	1.48	1.34	1.30	2.40	1.47	.28	1.36	14.51
1912	.28	1.43	.78	2.49	2.86	3.39	3.58	1.58	1.88	1.99	.18	.29	20.73
1913	.22	.40	1.57	2.19	1.44	1.35	1.85	1.14	2.08	.34	.30	3.67	16.55
1914	.03	.32	.20	4.01	1.46	3.54	1.66	1.05	.23	2.08	.10	.90	15.58
Normal[2]	.18	.51	1.33	2.79	2.54	2.34	3.02	2.14	1.65	1.36	.61	.78	19.25

[1] T.=Trace.
[2] Normal precipitation, October to March, inclusive, is 24.8 per cent of the normal for the year.

In the consideration of the time of plowing, the great variation in time and amount of precipitation must be kept in mind. The winter precipitation is usually in the form of snow, and wind is an important factor in its local distribution. Heavy rainfall or snows that are not disturbed by wind may occur between November 1 and April 1, but as the ground is usually frozen the amount of moisture stored in the soil from them apparently would not be affected by the time of plowing. Generally, the greater part of the snowfall will be blown off of a fall-plowed field, while a considerable quantity will be held by stubble land.

Rains in August and early September invariably produce a growth of weeds, which usually exhaust the available soil moisture, a ton of Russian thistles using 65 per cent as much water as would be used in producing a ton of unthrashed wheat.[1] The loss of moisture which has penetrated to a greater depth than 3 inches after the weeds are dead in the fall and before growth starts in the spring is almost negligible, either from land fall plowed or from that covered with stubble. Light precipitation evaporates, unless it falls as snow which is blown into drifts until a considerable quantity has accumulated. As 10 inches of light snow is the equivalent of only 1 inch of rain and 1 inch of rain penetrates the surface soil to a depth of 6 inches, it will be readily seen that snows of 1 to 5 inches supply a very small amount of moisture, the greater part of which will be lost by evaporation.

While the normal precipitation of the six months from October to March, inclusive, is only 25 per cent of the normal annual, the highest recorded precipitation for any month, with one exception, is 5.45 inches in March, 1905. In five years of the ten recorded the precipitation in March has been less than 0.5 inch. The precipitation in the winter months has varied almost as much, in some years there being only snow flurries, while in others the snowfall sometimes totals 20 inches in a month. There has been a wider variation in the precipitation of the fall and winter, when moisture should be stored, than in the growing months.

Early fall rains will be used by weeds unless the land is cultivated. Heavy winter snows may occur, but they are likely to blow off the fields unless there is either stubble or an uneven surface to hold them. The time and method of cultivation, then, should be planned to prevent weed growth and still leave the soil or stubble in such a condition that it will hold the maximum of snow. The period when labor is available will also be an important factor in determining the time of plowing. When labor is scarce, cultivation other than plowing, which will kill weeds and can be done rapidly, may be resorted to. If this cultivation leaves the stubble on the surface or leaves the surface rough enough to hold snow, it may have even greater value than plowing. Disking or listing in the fall are the methods most commonly used.

EXPERIMENTAL WORK.

The experiments in crop-rotation and cultivation methods at Akron afford an opportunity for a number of comparisons between fall plowing and spring plowing. In this paper only the time of plowing after small grain will be discussed.

The practice has been to plow as early as practicable after harvest. The soil is then packed with a disk set straight and weighted. This

[1] See Briggs, L. J., and Shantz, H. L., Bulletin 284 of the Bureau of Plant Industry, entitled "The Water Requirement of Plants. I.—Investigations in the Great Plains in 1910 and 1911."

leaves the surface somewhat rough and tends to pack the furrow slice down on weeds or trash plowed under. The spring plowing for small grains has been done as early as weather conditions would permit and packed in the same manner as the fall plowing. Plowing for corn has been deferred until planting time.

Table II presents the results with spring wheat on fall-plowed and spring-plowed oat stubble in two similar 3-year rotations, Nos. 4 and 9, and from both the fall and the spring plowing of land continuously cropped to wheat. In this latter comparison the fall plowing is deeper than the spring plowing, but this difference has not apparently affected the results sufficiently to prevent their comparison in a study of the effects of time of plowing.

TABLE II.—*Annual and average yields of spring wheat from fall-plowed and spring-plowed plats at the Akron Field Station, 1909 to 1914, inclusive.*

Treatment.	Rotation No.	Yield per acre of grain (bushels).						
		1909	1910	1911	1912	1913	1914	Average.
Fall plowed:								
Oat stubble	4	10.6	4.6	6.7	18.8	0.3	13.8	9.1
Wheat stubble	B	10.3	6.2	4.1	20.7	.8	12.2	9.1
Average for fall-plowed plats		10.5	5.4	5.4	19.8	.6	13.0	9.1
Spring plowed:								
Oat stubble	9	14.3	6.3	.2	20.3	1.0	21.2	10.6
Wheat stubble	A	14.3	11.3	2.9	21.3	4.8	22.2	12.8
Average for spring-plowed plats		14.3	8.8	1.6	20.8	2.9	21.7	11.7
Gain or loss of spring-plowed over fall-plowed plats		3.8	3.4	−3.8	1.0	2.3	8.7	2.6

Table III presents in similar form the yields of oats from fall-plowed wheat stubble in rotations Nos. 1 and 3, from spring-plowed wheat stubble in rotation No. 2, and from both the fall and the spring plowing of land continuously cropped to oats.

TABLE III.—*Annual and average yields of oats from fall-plowed and spring-plowed plats at the Akron Field Station, 1909 to 1914, inclusive.*

Treatment.	Rotation No.	Yield per acre of grain (bushels).						
		1909	1910	1911	1912	1913	1914	Average.
Fall plowed:								
Wheat stubble	1	25.6	15.9	13.6	56.8	7.2	35.9	25.8
Do	3	15.6	13.0	14.8	40.0	4.7	36.6	20.8
Oat stubble	B	14.1	8.0	15.9	46.9	.6	36.9	20.4
Average for fall-plowed plats		18.4	12.3	14.8	47.9	4.2	36.5	22.4
Spring plowed:								
Wheat stubble	2	18.3	14.8	1.7	46.9	16.6	47.5	24.3
Oat stubble	A	21.1	10.9	4.3	41.9	6.6	39.4	20.7
Average for spring-plowed plats		19.7	12.9	3.0	44.4	11.6	43.4	22.5
Gain or loss of spring-plowed over fall-plowed plats		1.3	.6	−11.8	−3.5	7.4	6.9	.1

Table IV presents the yields of corn from fall-plowed oat stubble in two rotations, from spring-plowed oat stubble in one rotation, and from both fall-plowed and spring-plowed wheat stubble in one rotation each.

TABLE IV.—*Annual and average yields of corn from fall-plowed and spring-plowed plats at the Akron Field Station, 1909 to 1914, inclusive.*

Treatment.	Rotation No.	Yield per acre of grain (bushels).						
		1909	1910	1911	1912	1913	1914	Average.
Fall plowed:								
Oat stubble	1	26.4	7.9	9.3	29.1	6.0	16.7	15.9
Do	3	25.7	5.0	9.2	34.3	0	14.7	14.8
Wheat stubble	4	23.1	4.6	4.7	34.3	0	7.6	12.4
Average for fall-plowed plats	......	25.1	5.8	7.7	32.6	2.0	13.0	14.4
Spring plowed:								
Oat stubble	2	26.3	7.6	1.2	33.7	10.3	17.4	16.1
Wheat stubble	9	25.3	12.4	0	37.5	0	12.6	14.6
Average for spring-plowed plats	......	25.8	10.0	.6	35.6	5.2	15.0	15.4
Gain or loss of spring-plowed over fall-plowed plats	......	.7	4.2	−7.1	3.0	3.2	2.0	1.0

Table V presents the yield of winter wheat from two continuously cropped plats, the plowing of which was sometimes early and sometimes late.

TABLE V.—*Annual yields of winter wheat from plats plowed at different dates at the Akron Field Station, 1909 to 1914, inclusive.*

Plat.	Plowing date and yield of grain (bushels).											
	1909		1910		1911		1912		1913		1914	
	Plowed.	Yield.	Plowed.	Yield.	Plowed.	Yield.	Plowed.	Yield.	Plowed.	Yield.	Plowed.	Yield.
A	Sept. 14	14.5	Sept. 18	11.4	Sept. 3	1.7	Sept. 8	25.8	Sept. 20	3.3	Sept. 30	24.5
B	Sept. 22	12.9	..do....	10.3	Aug. 12	6.8	Aug. 15	26.7	Sept. 18	2.0	..do....	24.8

SOIL MOISTURE.

Some of the factors determining the yields of small grain are apparent to the casual observer. One of these is the greater number of weeds growing with the grain crop on fall-plowed land at the Akron Field Station.

Another factor not so readily seen is the moisture content of the soil at the time of seeding. A knowledge of the exact percentage of moisture in the soil is not necessary. While the water-carrying capacities of soils vary with their composition and compactness, it may be taken as a working hypothesis that on the hard land of eastern Colorado the relative depths to which water has penetrated on different fields is a fair approximation of the relative amounts of water available on them. For example, if one field is found to be wet to a depth of $1\frac{1}{2}$ feet and a second is wet to a depth of 3 feet it may be assumed that the second field has approximately twice as much water in it as the first field. In the discussion of soil moisture as related to time of plowing it is not necessary to consider the hygroscopic moisture, which is not available to the plants.

Wheat plants at Akron readily root to a depth of 5 feet if the soil is wet from the surface to that depth and if there is not a more easily obtained supply nearer the surface. This soil will hold an average of $1\frac{1}{3}$ inches in each of the upper 5 feet, so that $6\frac{2}{3}$ inches of precipitation may be stored for the use of the crop. This would be sufficient under favorable wind and temperature conditions to produce a crop of 10.7 bushels of wheat per acre.[1]

In order to study the relative efficiency of different times of plowing in the accumulation of moisture in the soil and the relation of the moisture in storage to crop production, moisture determinations have been made at more or less regular intervals.[2] A continuous record of the moisture content is available for only two plats under discussion. These are plats A and B, continuously cropped to spring wheat, and are probably representative in their moisture relations of all spring-plowed and fall-plowed plats, plat A being continuously spring plowed and plat B continuously fall plowed.

In Table VI are presented the data obtained in making the moisture determinations on these plats. The moisture content is shown in percentages of the dry weight of the soil. For example, 10 per cent means that for every 100 pounds of dry soil there are 10 pounds of water. In the table are shown the total water content at the time of sampling, the nonavailable water, or that which can not be utilized by the plants, and the water available for the use of the plant.

The total water content needs little explanation. It is determined directly by weighing the sample of soil, drying it thoroughly, reweighing, and determining the loss in weight. The difference in weight represents the amount of water.

As water from the soil is used by the crop and the soil becomes drier, a point is reached below which the plants can obtain no more water. This point is called the "minimum point of exhaustion," and the amount of water remaining in the soil below this point is termed "nonavailable." The minimum point has been determined by observing the behavior of the crop on the plat and by frequent sampling. By continuing such study through several years the minimum point can be determined quite accurately.

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[1] See Briggs, L. J., and Shantz, H. L., op. cit.

[2] Moisture determinations are made through the cooperation of the Office of Dry-Land Agriculture and the Biophysical Laboratory.

Table VI.—*Total, nonavailable, and available water in spring-wheat plats A and B on different dates at the Akron Field Station.*

[Data in percentages of dry weight of soil.]

Plat and depth.	1908	1909		1910		1911			1912			1913			1914	
	Aug. 27	Apr. 7	Aug. 25	Mar. 17	July 18	Apr. 8	Aug. 15	Oct. 30	Apr. 9	Aug. 7	Oct. 29	Apr. 5	July 24	Oct. 2	Mar. 24	July 20
Plat A (spring plowed):																
1 foot: Total	9.4	25.8	15.3	20.7	6.9	10.8	7.9	11.7	21.8	14.3	14.8	19.2	18.0	11.7	19.1	8.8
1 foot: Nonavailable	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
1 foot: Available	2.4	18.8	8.3	13.7	0	3.8	.9	4.7	14.8	7.3	7.8	12.2	11.0	4.7	12.1	1.8
2 feet: Total	11.8	21.7	15.2	17.5	11.5	12.5	11.3	11.5	22.9	13.9	12.6	13.8	14.1	12.3	17.6	11.2
2 feet: Nonavailable	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
2 feet: Available	.3	10.2	3.7	6.0	0	1.0	0	0	11.4	2.4	1.1	2.3	2.6	.8	6.1	0
3 feet: Total	9.6	12.7	11.4	12.5	10.2	10.4	9.0	9.3	19.3	10.7	10.1	10.7	9.5	9.3	10.0	9.1
3 feet: Nonavailable	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3
3 feet: Available	.3	3.4	.1	1.2	.9	1.1	0	0	10.3	1.4	.8	1.4	.2	0	.7	0
4 feet: Total	....	9.2	11.2	10.4	9.8	9.4	8.0	7.9	14.2	10.4	8.9	9.5	8.9	8.0	8.2	8.3
4 feet: Nonavailable	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
4 feet: Available	....	1.2	3.2	2.4	1.8	1.4	0	0	6.2	2.4	.9	1.5	.9	0	.2	.3
5 feet: Total	....	8.6	11.7	9.7	9.8	10.6	8.3	8.0	15.6	9.5	9.6	9.9	10.0	8.7	8.2	8.5
5 feet: Nonavailable	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2
5 feet: Available	....	.4	3.5	1.5	1.6	2.4	.1	0	7.4	1.3	1.4	1.7	1.8	.5	0	.3
6 feet: Total	....	7.6	11.7	9.1	9.6	7.3	8.5	8.8	12.3	11.7	11.0	10.0	10.6	8.5	8.1	8.1
6 feet: Nonavailable	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6
6 feet: Available	....	0	4.1	1.5	2.0	0	.9	1.2	4.7	4.1	3.4	2.4	3.0	.9	.5	.5
Plat B (fall plowed):																
1 foot: Total	9.6	25.3	14.5	16.0	6.4	13.6	9.9	14.4	19.4	10.8	17.6	15.9	12.8	10.5	17.6	7.4
1 foot: Nonavailable	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
1 foot: Available	2.6	18.3	7.5	9.0	0	6.6	2.9	7.4	12.4	3.8	10.6	8.9	5.8	3.5	10.6	.4
2 feet: Total	10.8	22.4	13.2	15.5	11.9	18.2	11.5	11.5	20.5	10.5	15.0	11.3	11.6	10.1	13.7	9.3
2 feet: Nonavailable	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
2 feet: Available	0	10.9	1.7	4.0	.4	6.7	0	0	9.0	0	3.5	0	.1	0	2.2	0
3 feet: Total	8.6	14.9	10.1	11.8	9.8	14.8	9.6	9.2	14.2	8.1	9.7	8.1	8.6	7.2	9.5	8.0
3 feet: Nonavailable	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3
3 feet: Available	0	5.6	.8	2.6	.5	5.5	.3	0	4.9	0	.4	0	0	0	.2	0
4 feet: Total	....	11.1	9.7	9.8	9.3	10.9	9.8	8.2	9.4	8.7	8.6	7.4	8.1	6.5	7.6	7.0
4 feet: Nonavailable	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2
4 feet: Available	....	2.9	1.5	1.6	1.1	2.7	1.6	0	1.2	.5	.4	0	0	0	0	0
5 feet: Total	....	10.0	8.1	9.1	8.7	9.5	10.4	8.9	8.4	9.7	9.1	7.5	8.2	6.6	7.5	6.4
5 feet: Nonavailable	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1
5 feet: Available	....	1.9	0	1.0	.6	1.4	2.3	.8	.3	1.6	1.0	0	.1	0	0	0
6 feet: Total	....	6.7	7.0	8.6	7.2	8.0	10.0	8.1	7.8	7.7	8.3	7.0	7.0	6.7	6.5	6.2
6 feet: Nonavailable	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
6 feet: Available	....	0	0	1.6	.2	1.0	3.0	1.1	.8	.7	1.3	0	0	0	0	0

The water available for the use of the plant is computed by subtracting the nonavailable water from the total water content. It is the available water in which the farmer is interested. This, together with the rainfall during the growing season, represents the total water supply for the production of crops. In order to show more clearly the available water, figure 1 has been prepared. In it are presented graphically the relative amounts of available water in each foot-section, as shown in Table VI. At the left of the figure is shown the depth represented in foot-sections from 1 to 6 feet. The dates the determinations were made are shown at the top of each column. Each division of the black column represents the percentage of water in that foot-section available for the use of the plants on that date.

As already stated, the percentages are computed on the dry weight of the soil, and, as the weight of the soil in the first foot is less than in those below, the percentage of moisture must be higher to indicate an equal amount of water. For example, the percentage of moisture on April 9, 1912, on plat A in the first foot was higher than for the second, but the actual amount of water in each of the 2 feet was the same. The weight per cubic foot of the lower 5 feet is nearly the same, so that a comparison of moisture percentages is also a direct comparison of moisture content.

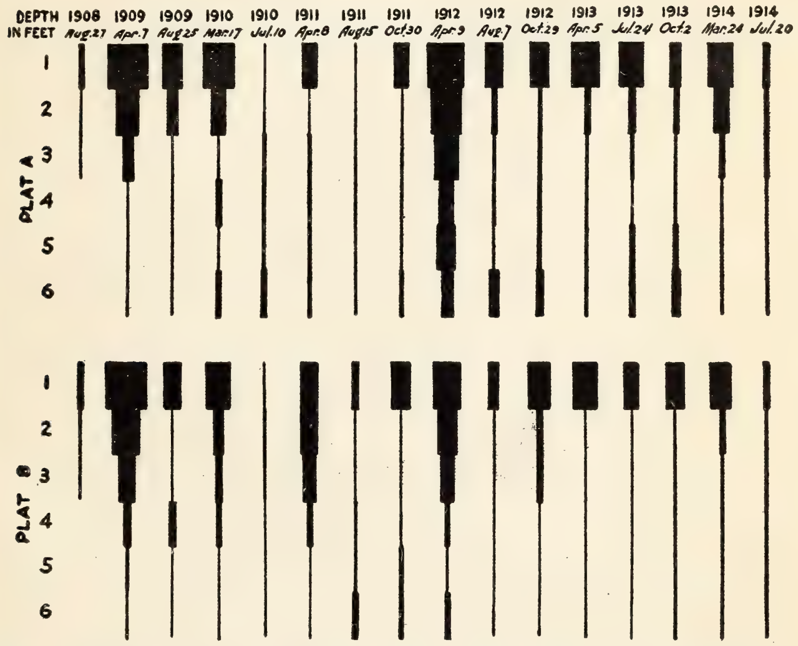

FIG. 1.—Graphs showing the amounts of water available to wheat in each of the upper 6 feet of soil at certain dates of sampling at the Akron Field Station, for the years 1908 to 1914, inclusive. Plat A is spring plowed, plat B is fall plowed, and both are continuously cropped to spring wheat.

A small percentage of moisture in any foot does not necessarily mean that the moisture was evenly distributed through that foot. It may have been contained in a few inches of one foot. The determinations of October 30, 1911, show 4.7 per cent in the first foot of plat A, all of which was probably in the upper 8 inches. The soil is usually exhausted of available moisture at the time the small grain is harvested. One exception to this was plat A, on August 7, 1912. The summer precipitation had been so heavy that all the water in the soil on April 9, 1912, had not been needed in the production of the crop. The spring sampling of April 7, 1909, showed a little higher moisture content in plat B than in plat A. The difference was in the third and fourth feet.

The sampling of April 17, 1910, shows a higher moisture content in the first and second feet of plat A than in the corresponding feet in plat B.

The sampling of April 8, 1911, shows about six times as much water in plat B as in plat A.

On April 9, 1912, plat A contained more than twice as much available moisture as plat B. As the greater part of the moisture in plat A was due to snow held by the stubble, it is probable that the snow melted and the stubble refilled several times during the winter, and as the increase in the moisture in this plat from October 30, 1911, to April 9, 1912, was greater than the precipitation during that period, the snow must have drifted on to this plat from adjacent fields.

The moisture in the soil on April 15, 1913, was all in the first foot. The amount in plat A was slightly greater than in plat B.

In the late fall of 1913 there was but little moisture in the first foot of plat B. This was slightly increased during the winter of 1913–14. Plat A contained much less water at the time of sampling in the late fall. There was an increase in the amount in the first, second, and third feet during the winter. The grain yield from plat A was 82 per cent higher than that from plat B, while the total yield of straw and grain was only 16 per cent higher.

In 1909, 1910, 1913, and 1914 there were but small differences in the moisture content of the two plats at the time of seeding, and in those years the better yields were from spring plowing. In 1911, when there had been a heavy precipitation the previous August, there was a very pronounced difference in favor of fall plowing. In 1912, when there was moisture to the depth of 6 feet in plat A and 3 feet in plat B, the yields were nearly equal. This was chiefly due to the heavy summer precipitation, which supplied the crop without its having to depend on stored water.

A comparison of annual yields from spring plowing and fall plowing shows considerable differences every year, except in 1912, when the summer precipitation was high enough to produce good yields with little or no stored moisture. In five years out of the six wheat and corn have averaged better on spring plowing than on fall plowing. In those five years there is not an instance where either the spring-plowed wheat or corn plats dropped below the average of the fall-plowed plats.

The oat yields each season show a slightly greater variation than do the yields of either wheat or corn, but still they must be considered consistent. In four of the six years the average yields from the spring-plowed plats were higher than those from the fall-plowed plats. These were the years when spring plowing gave the better results with both wheat and corn. The only year that oats gave a higher yield from fall plowing, when wheat and corn gave higher yields from spring plowing, was 1912. This was a year when the yields of oats were near the maximum in that locality for the variety used—Kherson. In only one year (1911) out of the six did fall plowing give the best results with all three crops. This also was the year in which early fall plowing gave a marked increase over late plowing with winter wheat.

The yields of winter wheat on plats A and B, presented in Table V, are of interest. Three years out of the six one plat was plowed earlier than the other. The condition of the surface of the plats during the winter was the same, both being devoid of stubble and equally level. The only important difference in treatment was the time of plowing. In all three instances the higher yields have been on the earlier plowing. The only marked difference, however, was in 1911, when the earlier plowing had been done immediately after heavy rains and a large growth of weeds occurred on the later plowed plat before it was plowed. In the three years when there was no difference in time of plowing there was no difference greater than 1.3 bushels in yields. While this was a difference of more than 60 per cent, it will be noted that both plats were practically failures in that year (1913). In the six years the only marked difference in yields was in 1911, when the plowing was done 22 days earlier on plat B than on plat A and plat B yielded 5.1 bushels more than plat A. Except when early plowing had stored moisture by stopping weed growth, there was no marked difference in yields. The late fall plowing usually lost available moisture by weed growth, which was not offset by a greater winter accumulation, as in spring plowing.

In studying each year separately it is necessary to consider the precipitation. Data on the moisture content of the soil in the fall and spring and at harvest time will aid in giving an idea of the relative importance of fall and winter precipitation and the amount used by the crop.

Figure 1 shows that in the fall of 1908, up to which time the plats had had uniform treatment, there was no moisture in the soil available to plants. August and September were very dry and plowing was not done until the weeds had been killed by frost. While there was heavy precipitation in November, 1908, and in March, 1909, the increase in moisture content was practically the same, the third foot of both plats being partially filled. Plat A gave a yield of 14.3 bushels, and there was still some moisture available at the time of harvest. The greater number of weeds growing with the wheat in plat B probably accounts for the greater loss of moisture and the smaller yield. This statement is borne out by the yields of corn, which were practically the same from both the spring and the fall plowing. The corn was given clean cultivation. The spring-plowed wheat plats averaged 3.8 bushels and the spring-plowed oat plats 1.3 bushels per acre more than the fall-plowed plats.

The heavy rains in August and early September in 1909 prevented thrashing and delayed fall plowing until the latter part of September. By that time the heavy growth of weeds had used the soil moisture resulting from the precipitation of August and September, and plat B plowed up dry and lumpy. No moisture determinations were made at this time, but it is only fair to assume that plat A was equally dry, as it also had produced a heavy growth of weeds. In the spring of 1910 the moisture content of plat A was decidedly greater in the first and second feet and slightly greater in the third foot than it was in plat B. This increase in moisture content was due to the snow held by the stubble on plat A. At harvest time the moisture was exhausted in both plats, but plat A gave a yield of 11.3 bushels and plat B yielded 6.2 bushels.

The small difference in moisture content in the spring could not account directly for the difference in yields, but the slightly larger amount of moisture in plat A may have caused a quicker growth, which crowded out the weeds. All three crops were better on spring than on fall plowing. The corn, in which weeds were not a factor in determining the yield, showed a difference in favor of spring plowing.

As the moisture in both plats A and B was exhausted at harvest time, their moisture content was probably the same when plat B was plowed, August 12, 1910.

The early plowing of plat B prevented weed growth on it, and the greater part of the heavy rains of August and September was stored until the following season. Practically all the water from these rains was used in the fall by a heavy growth of weeds that occupied the plats which were to be spring plowed. Light precipitation during the winter of 1910–11 added very little water to the soil; consequently the spring-plowed plats had much less moisture in the spring than the fall-plowed plats. The yield was 4.1 bushels of wheat from plat A and 15.9 bushels from plat B. All the moisture had been used from both plats. Every fall-plowed plat gave a better yield than was obtained from any spring-plowed plat.

Plat B was plowed on August 16, 1911, immediately after a rain of 1 inch. There were only light rains during August and September, which slightly increased the moisture content of the first foot in plat B but made no change in plat A. The heavy snows of February and March were held by the stubble on plat A. In melting they filled its soil to a depth of at least 5 feet. There was no change below the third foot in the water content of plat B.

The precipitation of the growing season was so heavy that none of the crops suffered from lack of moisture. The yields from fall plowing and spring plowing were nearly equal. At harvest there was a small amount of moisture in plat A to a depth of 6 feet, while that in plat B had been exhausted.

The remainder of the moisture in plat A was used by weeds, and at the time plat B was plowed, September 18, 1912, the moisture in both plats was equal. In the spring of 1913 the first determination showed there had been a slight increase in the water content of plat A to a depth of 3 feet, while there had been an increase in only the first foot of plat B. The water in plat B was so nearly exhausted by the first week in June that the crop was burned beyond recovery, while plat A had water enough, supplemented with a light precipitation, to produce 4.8 bushels of wheat. The yields from all plats were very low, but the average yield was higher for all three crops on spring plowing.

The light precipitation of August and September, 1913, did not put the soil in condition for plowing until October 14. There was very little weed growth in the fall and the sampling of October 2 shows very little stored water. The water content of plat A in the spring was twice as great as that of plat B, but neither had an appreciable amount of available water below the second foot. While there was but a small difference in the moisture content of the two plats, the yield of grain from plat B was only 55 per cent of that from plat A. The yield of straw was the same from each. The slight difference in water content in favor of plat A, with the smaller number of weeds in the grain and a normal precipitation during the growing season, had enabled it to produce a good crop of grain, while plat B had dried up before maturing.

SUMMARY.

The average yields from spring and from fall plowing show that the blind following of a rule prescribing any particular time of plowing might cause a reduction as often as it does an increase in the yields of the three spring crops of wheat, oats, and corn. The very small difference in yield each year from plats plowed at the same time, when compared with the greater difference from plats plowed at different times, indicates that the time of plowing is one of the most important of the controllable factors in crop production.

The great variation in the time and amount of precipitation is the important climatic characteristic of this region in eastern Colorado that must be kept constantly in mind when considering the time of plowing. No dependence can be placed on a heavy precipitation in August and September, yet it frequently occurs. When there is such precipitation, measures should be taken to conserve it. Weeds being the important factor in its dissipation, cultivation to destroy them should be given as soon as possible after the occurrence of rains in

those months. Precipitation that comes after the weeds are killed by frost in the fall is as well stored by soil covered with dead weeds as by a turned furrow. Usually there is greater increase in moisture content in the spring-plowed plats during the winter than there is in the fall-plowed plats. This is due to the snow held by the stubble on the land which is to be spring plowed. Sometimes there is a very decided increase of the moisture in the spring-plowed land, which, with a normal summer precipitation, makes a great difference in yields.

Moisture content in the spring is but one of the factors in the production of grain crops. Weeds growing with the crop may use enough water to decrease the grain yield materially. Fall plowing at the Akron station is especially favorable to weeds starting with the grain. Plowing in the spring thoroughly eliminates the weeds and, if done immediately before seeding, gives the grain crop the start of them. No other cultivation is so effective in destroying weeds as plowing. The ideal cultivation would prevent weed growth in the fall, leave the land in such a condition that it would retain the maximum of snow in the winter, and retard the germination of weed seed until the crop starts in the spring.

Early fall plowing effectively destroys weeds which use the early fall precipitation, but it does not leave the land in condition to retain the snow in the winter and it gives the weeds an opportunity to start before the crop. Spring plowing leaves the stubble to retain snow and reduces the number of weeds in the growing crop, but it does not prevent the loss of moisture by weed growth in the fall.

In deciding the time to plow, the advantages and disadvantages of both spring plowing and fall plowing must be taken into consideration. Heavy rains in August indicate that fall plowing should be done, as the gain in moisture during the winter by stubble land probably would not equal the loss by weeds in the fall. If only light rains occur, their loss probably would be more than offset by the greater quantity of snow held by the stubble during the winter and the reduction of the weeds in the crop. Spring plowing would then be the better. The availability of labor in the fall will influence the amount of plowing done, but a greater effort should be made to do the plowing if there is heavy precipitation than if it is light. The only advantage in late fall plowing is that the amount of spring labor in preparing a seed bed is reduced. This advantage may be offset by a reduction in yield.

CONCLUSIONS.

(1) Early fall precipitation is used by weeds if land is left uncultivated until spring.

(2) Stubble prevents much of the winter snow from being blown off. The increase in soil moisture from this source usually more

than compensates for the loss by weed growth of the precipitation of August and September, when such precipitation is light.

(3) Late fall plowing does not prevent the loss of early fall precipitation through weed growth, but it does destroy stubble, which would aid in holding winter precipitation.

(4) If heavy rains occur in August or September, plowing should be done immediately after they cease. If this can not be done, or if heavy rains do not occur, the land should be left in stubble until the following spring.

(5) The ideal cultivation would prevent weed growth in the fall, leave the land in condition to retain the maximum quantity of snow in the winter, and thoroughly destroy small weeds immediately before seeding. Possibly this may be accomplished by disking in the fall and plowing in the spring, or listing in the fall and bursting the ridges in the spring may prove practicable.

(6) In deciding when a field in this part of eastern Colorado should be plowed, the question whether a greater amount of water will be accumulated from snow than will be dissipated by weeds is paramount and must be decided by the man on the ground.

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